Wave Interaction with Large Topographic or Man-made Structures

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LONG-TERM GOALS

To study, by fluid mechanical theories, the interaction of ocean surface waves with structures, either natural (sandbars, harbors, coastline) or man-made (offshore airports, breakwaters). Factors of natural environment (wind, sediments) that are integral parts of the physical process are included.

OBJECTIVES

For the present grant the immediate goals are to examine:

1. Various resonance mechanisms that can lead to large wave loads around a structure. In the current year, efforts are focussed on a structure with periodic components, with the ultimate view to studying a floating airport supported by many submersibles.
2. Mechanisms of generating periodic sandbars on the seacoast which may be of importance to small-scale naval operations.

Area 1: Trapped Modes Around a Periodic Structure

APPROACH

Stimulated in part by possible interests in Mobile Offshore Bases, we have extended our recent work on Venice Gates, to examine possible resonances around a periodic structure of complex geometry. The first step is to calculate the eigen-modes and eigen frequencies according to the linear potential theory. As a test case we have nearly completed the eigen-modes for prototype Venice Gates, which are inclined at 50 degrees from the horizon, have a complex cross sectional shape and rest on housing which is not flat on the seabed, as shown in Figure 1. Our method is to extend the hybrid finite element method of Chen and Mei (1974) where the neighborhood of the complex structure is discretized into finite elements but the far field is represented analytically by eigen-function expansions. The basis of computation is to replace the boundary value problem (partial differential equations and boundary conditions) by a variational principle whose stationary functional consists of integrals over the near field only. By extremizing the functional with respect to the unknown nodal coefficients of the finite elements and the unknown coefficients of the eigen-functions, a set of linear algebraic equations is found which can be solved by a computer.

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RESULTS

In last year's report for N00014-92-J-1754, we described our theory and laboratory experiments on the subharmonic resonance of Venice Gates of an idealized geometry (Sammarco et al, 1997, a, b). Each of the gates is a rectangular box standing upright when in equilibrium; the seabed is horizontal. The sea levels on both sides were taken to be equal. With the new numerical method we are now able to study the effects of prototype cross section, unequal depths, changing angles of inclination and gate thickness and widths, on the eigen-frequency. A limited number of experiments have been performed at Delft Hydraulic Laboratory in 1988 to find whether the eigen-period can be shifted outside the peak of the incident sea spectrum. We have found that the eigen-period increases with the gate width, the water depth differences on both sides of the gate, and with the inclination from the horizon, and decreases with the gate thickness. A sample figure of the prediction and comparison with available experiments is presented in Figure 2.

IMPACT/APPLICATIONS

The above information can be useful to the designers of Venice Gates. Besides this research opens the way to extend the hybrid finite element method for finding trapped modes around ANY periodic structure. In recent years David Evans and associates at University of Bristol have studied analytically wave trapping near simple structures such as a line of vertical cylindrical columns. We shall soon embark on the prediction of trapped modes near a cluster of vertical cylinders such as the legs of an offshore tower.

Area 2: Wave Induced Formation of Sandbars

APPROACH

Sea waves are known to generate sandbars with crest parallel to the coastline. From the hydrodynamics of monochromatic waves over a flat and rigid bed, it has been known that the Reynolds stresses in the bottom boundary layer drives periodic cells if the waves are strongly reflected. Ms. Jie Yu is completing a Ph.D. thesis that couples wave hydrodynamics of the benthic layer with the bed load movement of sand. From large-scale experiments and field observations in Chesapeake Bay, it is known that small-scale ripples are but a small feature. Therefore, in our theory ripples are only treated as roughness of the seabed. Bed shear stresses are calculated as a function of the bar profile. The calculated bed shear stress then forms the forcing function of the sediment transport equation, in which the transport rate is related to the local shear stress by an empirical law well established for steady flows, but modified to account for gravity effects on a sloping bed. This leads to a diffusion equation where the diffusivity D is related to the gravity and forcing function F is related to the fluid stress.

RESULTS

We are studying the local effects within a wavelength and the global effects over many wavelengths of sandbars. First, the local phenomenon. In Figure 3, we display the forcing function and the diffusivity D beneath one wavelength of a partially standing wave. It can be seen that the source function is the greatest under the nodes and weakest near two sides of the antinodes. The diffusivity D is large beneath the node where mass transport converges, and is small beneath an antinode from which mass transport diverges. It follows that bar crests are formed beneath the node but the growth is ultimately limited by diffusion because of gravity. For nearly complete reflection R = 1, there is a short stretch beneath the antinode where the horizontal shear stress is so small that sand is not moved at all. We show in Figure 4 the transient growth of bars. For small reflection, erosion occurs everywhere; the bar profile is nearly sinusoidal. For strong reflection R=0.7 and 0.9, erosion is weak near directly beneath the antinode, hence the scour at the middle of the bar trough is slow. In the coming year we shall extend to the global problem of bar formation due to passage of waves over a long stretch of originally plane and erodible seabed, and see how Bragg resonance can create many bars.

IMPACT/APPLICATIONS

Because the formation of bars is a forced diffusion process, it is drastically different from the formation of small-scale ripples whose typical wavelengths are only dozens of centimeters. Specifically in our study last year, we showed that ripples are generated by instability of the sandy bed under an oscillatory boundary layer (Mei & Yu, 1997). Mathematically ripples correspond to the solution of a homogeneous eigen-value problem. Our progress suggests many further extensions, such as bars on a sloping beach. On the practical side, sand bar formation or disappearance is not only of interest to coastline geomorphology but also to naval operations. The first research for the military on sandbars was done prior to the Normandy landing of Allied troops near the end of WWII.

RELATED PROJECTS

Under the Massachusetts Institute of Technology (MIT) Undergraduate Research Opportunity Program (UROP), undergraduate Tim Harrison has been supported on a hourly basis, since January 1998, on our ASSERT grant N00014-95-1-0840 to assist in laboratory observations of sand ripples and bars in a small wave tank. Tim and Ms. Jie Yu, who is conducting research for a Ph.D. thesis on sandbars and ripples, together have found decisive evidence that ripples and bars can coexist in small scale situations in the laboratory, unlike the situation along a natural coastline where ripples are but a small feature on much larger zones. This finding has helped resolving certain uncertainty in the theory**.**

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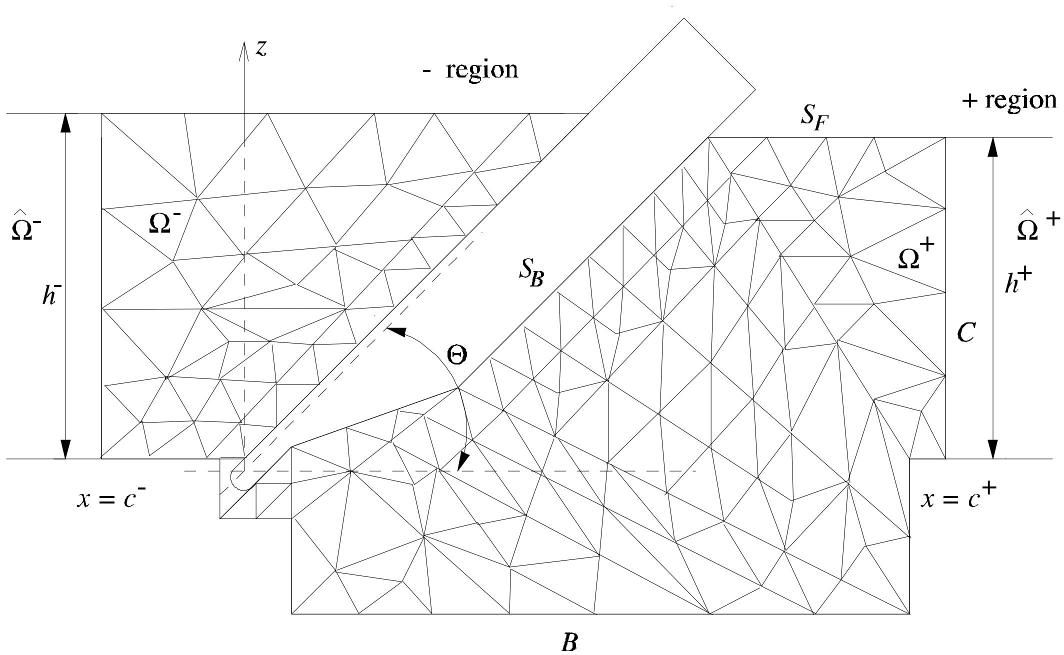

Figure 1. Cross section of a prototype Venice Gate, and finite elements. 20 to 40 identical gates span each of three inlets of Venice Lagoon.

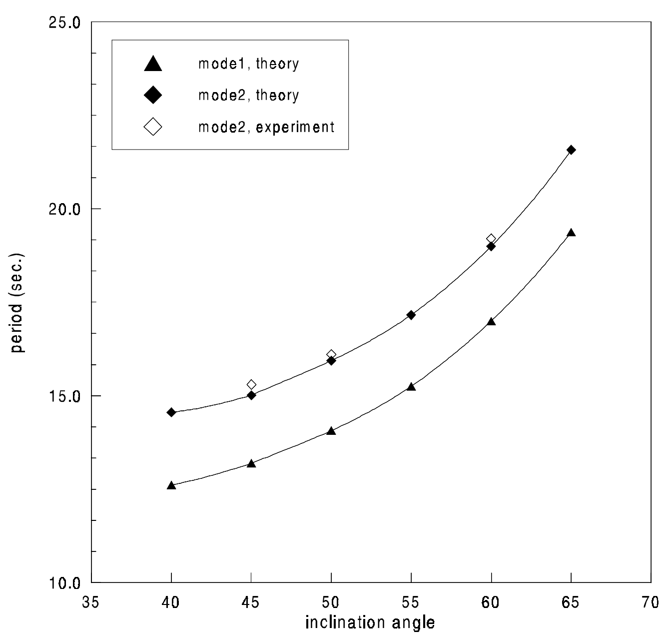

Figure 2. Natural frequencies for Mode 1 (+ - + -) and Mode 2 (- ++ - ++ -). Solid dots: theory; hollow dot, experiment.

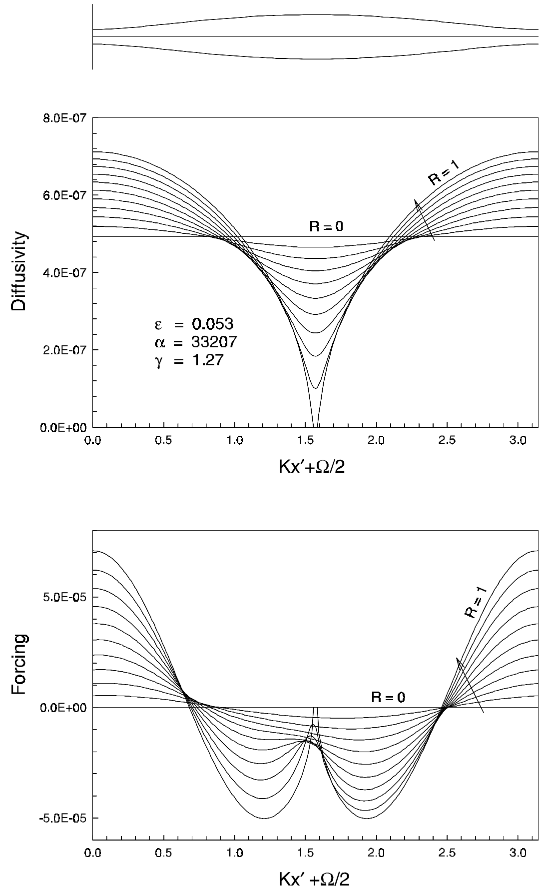

Figure 3. Top: Envelope of partially standing wave. Middle: Gravity-induced diffusivity D. Bottom: Forcing function F, for the evolution of sandbar. Reflection coefficient R = 0 (0.1) 1.0. Positive forcing corresponds to accumulation; negative forcing to erosion.

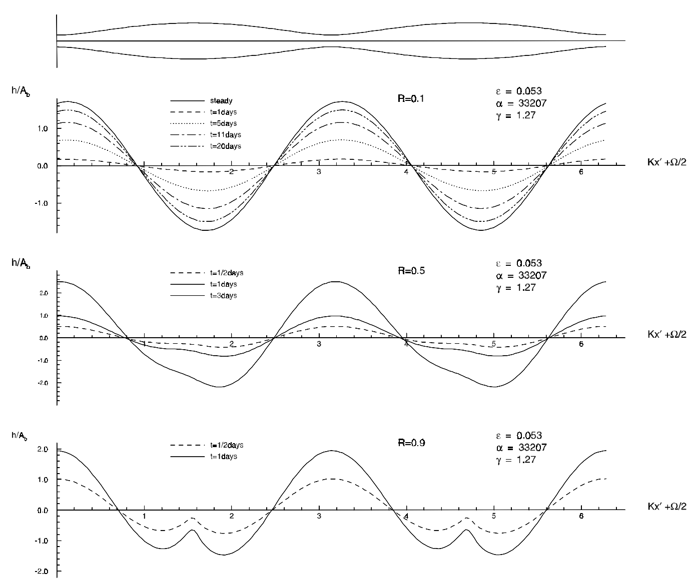

Figure 4. Transient evolution of sandbars under sample wave condition, for different reflection coefficients R. From top to bottom: wave envelope, R=0.1, 0.5 and 0.9.